Issued April 6, 1912.

U. S. DEPARTMENT OF AGRICULTURE,

OFFICE OF PUBLIC ROADS—BULLETIN No. 43.

LOGAN WALLER PAGE, Director.

HIGHWAY BRIDGES AND CULVERTS.

BY

CHARLES H. HOYT, C. E.,

Formerly Superintendent of Construction, in charge of Bridge Engineering, Office of Public Roads,

AND

WILLIAM H. BURR, C. E.,

Professor of Civil Engineering, Columbia University, Consulting Engineer, Office of Public Roads.

[Revision of Office of Public Roads Bulletin 39.]

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1912.

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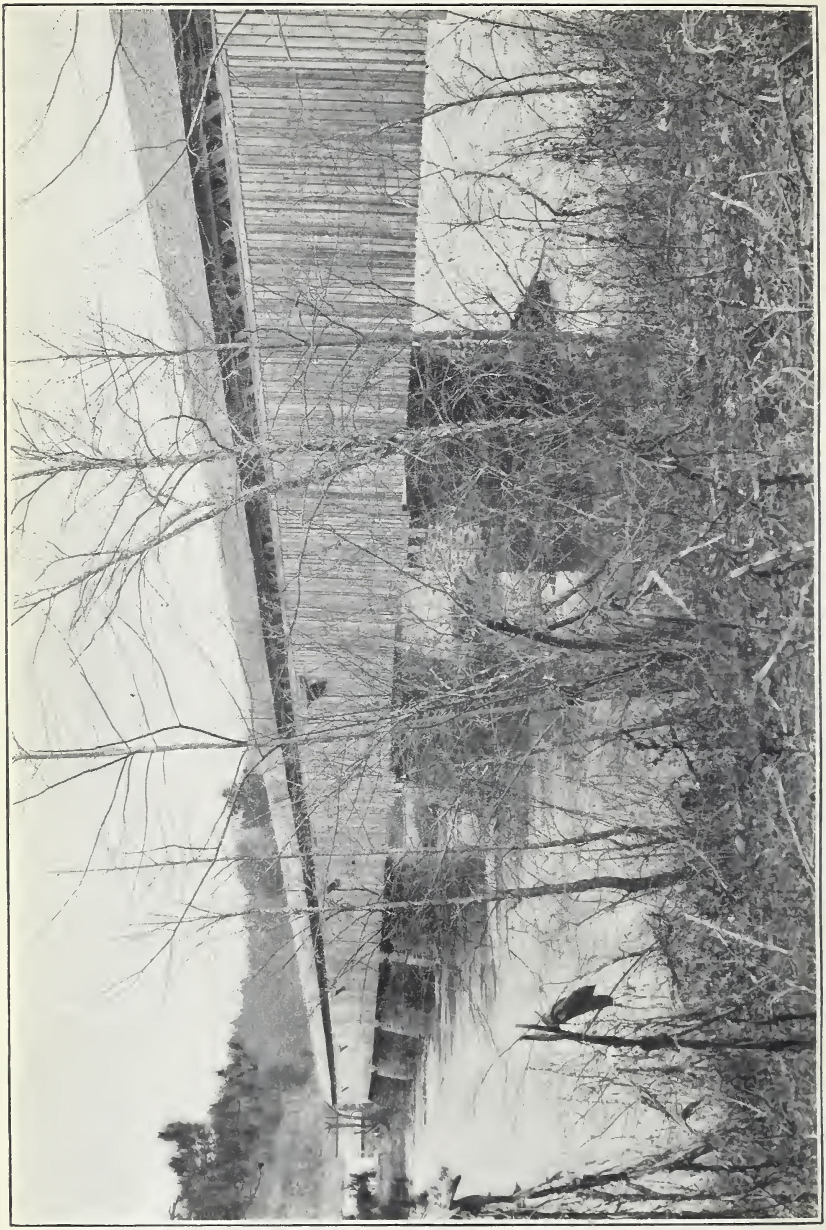

A GOOD SPECIMEN OF THE OLD TOWNE WOODEN LATTICE BRIDGE, LOCATED NEAR ROSWELL, GA.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Public Roads,
Washington, D. C., December 22, 1911.

Sir: I have the honor to transmit herewith the manuscript of a revision of Bulletin No. 39, entitled, "Highway Bridges and Culverts," by Mr. Charles H. Hoyt, formerly superintendent of construction in this office, and Mr. William H. Burr, professor of civil engineering, Columbia University, consulting engineer and expert on bridge construction for this office. The importance of this subject is beginning to receive the recognition it demands in consequence of its relation to the general movement for the improvement of our public highways. This document is the first of several publications which the office expects to issue in the near future, and for this reason it is rather a general treatment of a subject which will be taken up in greater detail in subsequent publications. I respectfully recommend that this manuscript be published as Bulletin No. 43 of this office.

Respectfully,

Logan Waller Page, *Director.*

Hon. James Wilson,
Secretary of Agriculture.

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HIGHWAY BRIDGES AND CULVERTS.

INTRODUCTION.

Bridge building in the United States is of comparatively recent accomplishment. The early settlers were compelled to ford the streams or cross them on rafts or in dugouts. When Washington crossed the Delaware with his army, there were no bridges over that river, and history records many instances of streams being forded with untold hardship and the consequent disasters and delays. Such incidents become serious matters when, for example, physicians are unable to reach the sick or injured because of impassable fords or are compelled to expose themselves to unnecessary danger. Traffic conditions in general are demoralized by unsafe bridges or culverts.

Pontoon bridges have served temporary needs in many instances, but especially in warfare. Mention is made of their use very early in history, and one of the most notable occasions was when the Persian army under Xerxes crossed the Hellespont on two pontoon bridges consisting, one of 360 vessels and the other of 314. These were anchored head and stern alongside each other, with their keels in the direction of the current.

The Romans had wickerwork vessels covered with hides destined to support the timber platforms of a bridge. These formed a part of the train of their armies throughout the history of the Empire until 476 A. D.

Nature has provided this country with at least nine natural bridges, which are situated as follows: One in Virginia, with a span of about 93 feet and about 200 feet high; one in Alabama, with a span of about 120 feet and about 70 feet high; one in Kentucky, with a span of about 70 feet and about 130 feet high; five in California, the largest of which has a span of about 80 feet and is about 20 feet high; and one in southern Florida of somewhat smaller dimensions.

The construction of highway bridges in this country began to assume practical proportions about the year 1800, when many wooden bridges were built in the Eastern and Central States by Theodore Burr and Timothy Palmer. The wooden lattice truss was introduced about 1820 by Ithiel Towne. Many of these bridges, consisting of planks pinned together in latticework, were built from this time on, and they became well known as "Towne" or "covered" bridges. It

is doubtful if much attention was given to economical design. An effort was made to protect the trusses from the weather, by wooden roofs and sides in some instances, but very few were ever painted to preserve the timber. This early type of bridge did service for many years, and some are still in existence. The frontispiece shows a view of one of these structures.

Few iron bridges were built in this country prior to 1850, and it was only in 1847 that the first publication in this country discussing the rational design of bridge members was issued by a Squire Whipple, of Utica, N. Y. Wrought iron began to replace cast iron about 1863, but steel was not used until about 10 years later. The advantage of steel over cast or wrought iron lies in its greater tensile strength.

Foremost among structures representing some of the attractive as well as substantial features in good bridge designing of the present age may be mentioned the Washington Bridge over the Harlem River in New York. This bridge has two middle arches of steel, each 510 feet in clear span, and seven masonry arches each with a 60-foot span. Its total length is 2,375 feet, while the width of its roadway is 80 feet and its height above mean high water is 151 feet. It was built at a cost of $2,850,000.

It is the purpose of this bulletin to point out some important fundamental principles that govern the operations necessary to secure properly designed highway bridges and culverts, and also to state briefly some facts relating to their construction. There is a great need throughout the entire country for more and better structures of this kind.

DESIGN.

Comparatively little attention has heretofore been given to the design of highway bridges, and the result has been disastrous in many instances.

A practice which has been in vogue and which has had an injurious effect, especially in the design of highway bridges, is the method of inviting bids upon the bidder's own plans without having a competent and disinterested engineer to pass upon the designs submitted. The total weight of the steel and the amount of shop work necessary to make good, strong connections determine largely the real as well as the economical cost of the bridge. The desire to secure the contract encourages the effort, under such conditions, to make the design light enough in weight to get the contract regardless of whether the bridge is designed to carry its load with a fair factor of safety.

Still a third matter which also has had an injurious effect upon the design of our bridges, and which should be avoided in all cases, is the determination of those acquiring the bridge not to pay more than a fixed amount, which has been decided in advance, without sufficient

information, such as reliable engineering inspection, preliminary plans, and estimates.

It is unfortunate that the practice of pooling bids has prospered as it has, and country highway bridges appear to have been a favorite subject for such operations, which destroy real competition. Where bidders furnish their own plans for bridges of this class, the unreliable bridge companies or dealers are encouraged to try to get consideration for their propositions. Then they usually succeed in securing the work so that they make an unwarranted profit, while at the same time they deliver a bridge which may not have been properly designed and for which the taxpayers have to pay. The only way that such conditions as these can be avoided with certainty is to employ a reliable engineer.

Sufficient has been said of the defects of the past in bridge construction to arouse the unwary purchaser, but the value of these facts would be small without suggesting a safer and more systematic course of procedure to those who have charge of the proposed bridge building. The plan to be observed should, therefore, consist of steps such as the following:

(1) The services of a capable bridge engineer should be secured.

(2) The foundation should be tested to determine its suitability, bearing power, and economy.

(3) The location should be determined within a close approximation, and a profile of the center line made, showing also the results obtained by testing the foundation.

(4) The loads which the bridge may be called upon to carry safely, anticipating reasonably the demands and growth of the future, should be decided upon. All highway bridges, at least those on main roads, should be designed to carry concentrated loads, such as road rollers or traction engines weighing from 10 to 15 tons each, with a reasonable factor of safety. Unfortunately for the traffic of to-day many of the present highway bridges were designed to carry only moderate uniform loads, and this accounts for their light appearance and their inadequacy to meet present demands.

(5) After these facts have been determined, the engineer will be able to prepare plans for the foundations, abutments, piers, and the bridge itself, all of which may be designed to meet economically the conditions of the location selected. An estimate of the cost may be made, and this should in all cases be used as the basis for an appropriation for the bridge.

Only by following some systematic method of procedure, based upon the fundamental principles mentioned, can a community secure the practical and economical designs which are necessary to make an intelligent and satisfactory expenditure of the funds appropriated for bridge construction.

The method of procedure for smaller culverts may be somewhat modified. This office has in preparation a set of standard designs for spans varying from 2 feet to 30 feet at intervals of about 2 feet. This is a range which is sufficient to include by far the greater number of the highway culverts built. To receive the benefit of these standards, application should be made to the Director of the Office of Public Roads, Washington, D. C.

FOUNDATIONS.

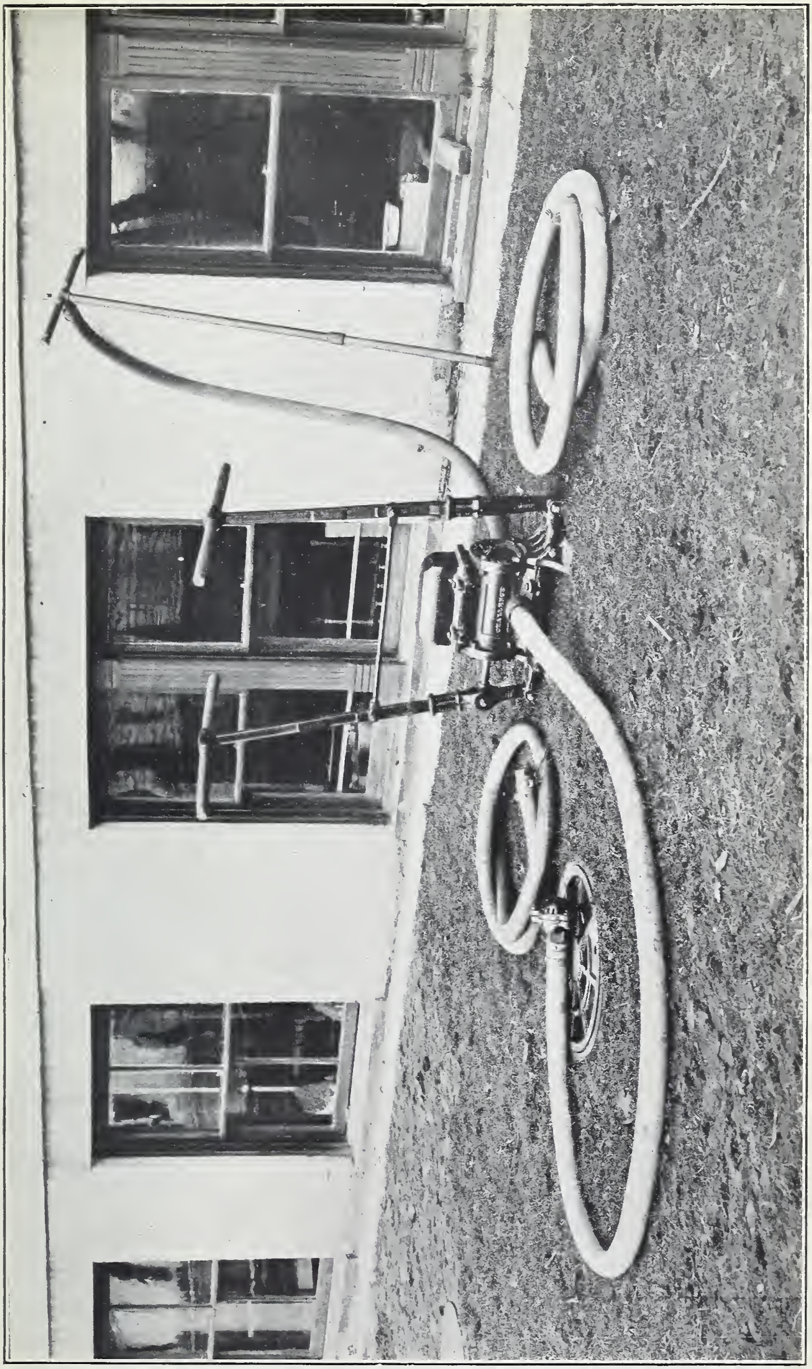
The question of foundations is much involved, and it is difficult to treat it satisfactorily in the limited space which can be given it here. The amount of attention and skill to be given to the foundations for any structure depends, first, upon the size and importance of the structure proposed, then upon the loads it must carry, and finally upon its type. To avoid misunderstanding, it may be stated that the word "foundation" is used throughout this bulletin to mean the natural bed or material upon which rest the footings for the piers or abutments for a bridge, or the walls or floor of a culvert. This bed may be either rock, sand, gravel, clay, or any other natural material, or an artificial foundation prepared of logs or other material, or it may be piles driven to support the structure.

For many of the smaller box culverts of spans varying from 2 feet to 8 feet and carrying only ordinary loads, the ordinary earth foundation is sufficient in most cases, with proper protection against undermining by currents of water. Where the streams are sluggish, however, or where the culverts are located in swamps and the foundations are soft and wet, a few logs from 10 to 12 inches in diameter, which are placed below in trenches and upon which the footings rest, add much to the stability of the foundation.

The logs, as shown in figure 1, may be placed close together, or in many cases it will be sufficient to place them about 3 feet apart, center to center. The advantages of this type of foundation are that it distributes the pressure and tends to prevent uneven settlement or tipping of the side walls.

The suitability of foundations for the more important structures can be safely determined only by tests. This can be done best by digging test pits wherever conditions will permit. In this way a better idea can be gained of the actual material in the foundation than by any other method.

Where conditions do not permit test pits, an iron rod may be driven to depths of from 10 to 20 feet, unless rock is encountered before that depth is reached. This method, however, gives very little idea of the material through which the rod is driven. A somewhat better way is to drive down 1-inch extra heavy iron pipe, which may be cut into 4-foot lengths and coupled together as



WASH-DRILL OUTFIT FOR TESTING FOUNDATIONS.

driven. A driving cap should be provided and the driving should be done with wooden mauls. Pipe has been driven in this manner in the winter months to depths of about 30 feet or possibly more. The pipe, after being driven, may be pulled out with a small chain and lever, so that a sample of the material through which the pipe was driven may be brought up inside it. This material can then be examined as the pipes are uncoupled and cleared out. Material that sticks in the pipe may be loosened by placing the 4-foot section of pipe in a small fire sufficient to generate steam from the moisture in the material, which, as it expands, forces the material out of the pipe. Great care should be exercised to have only sufficient fire to generate the steam slowly, or otherwise the material may shoot out of the ends of the pipe like a gun, or the pipes may burst or fly out of the fire with sufficient force to injure anyone standing near.

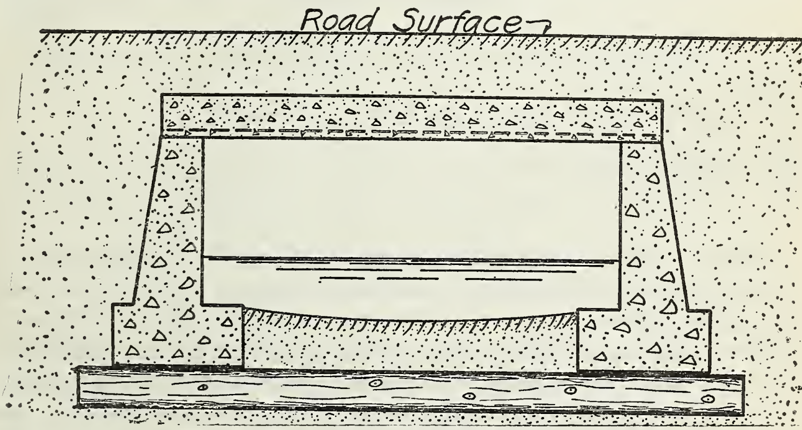


FIG. 1.—Use of logs in foundations.

One of the best ways to test a foundation is with a wash-drill outfit, consisting of a drill point to which is coupled 1-inch iron pipe in 4-foot lengths. Water is forced through this pipe by a double-acting force pump operated by one or two men. Tests have been made with such an outfit to depths as great as 60 feet. The wash-drill may be used with or without a jacket pipe. If a jacket pipe is used, it should consist of light weight iron pipe about 3 inches on the inside diameter, cut into 4-foot lengths, which may be coupled on as the pipe sinks into the ground. The benefit of the jacket pipe is that it preserves the boring for future use and that the material inside the pipe is washed up to the surface so that it may be examined.

Plate II shows a wash-drill outfit owned by the Office of Public Roads, which has been supplied to the office for its own work, and which consists of a double-acting force pump, with a cylinder 5 inches in diameter, a 5-inch stroke, a 2-inch suction, and a $1\frac{1}{2}$-inch discharge. The pump is fitted with two 12-foot lengths of suction

hose with a strainer, two 12-foot lengths of pressure hose, twelve 4-foot lengths of 1-inch extra heavy iron pipe, and a drill point.

The kind of material in the foundation determines to some extent the size of the footings for the structure, with due consideration to the weight to be borne and the bearing power per square foot of the material. Rock makes the best foundation and should be used when it occurs at available elevations.

A great many tests have been made to determine the bearing power of other materials, and, while there is much variation in results, the following figures are given as indicating the range of values obtained and, in the absence of more definite information, they may be used as allowable working loads:

Material.	Bearing power (tons per square foot).
Quicksand and wet soils	0.05 to 1.0
Dry earth	1 to 1.5
Moderately dry clay	2 to 4
Dry, stiff clay	4 to 6
Sand	2 to 4
Sand, compact and cemented	4 to 6
Gravel, cemented	8 to 10
Rock	200

There is, however, no definite rule by which the bearing power of a material can be determined absolutely without applying test loads and noting the amount of settlement caused by them. With the smaller highway bridges and culverts, which are the commonest built, an experienced builder is usually governed by his experience and good judgment concerning the suitability of a particular foundation to carry the proposed structure, but for any structure involving a considerable expenditure a careful test should be made.

Arch bridges or culverts especially require an unyielding foundation and are more than likely to fail unless such is provided. Consequently, they should not be built except where a good rock or gravel foundation is to be had, or possibly where a satisfactory foundation can be made by driving piles. Attention should be called to the fact that piles may be driven in an inclined position, and thus be able to resist the arch action directly.

The bearing power of piles may be determined for practical purposes, where comparatively stiff material is found, by the following formula:

$$\text{Safe load} = \frac{2\ WH}{S + 1}.$$

Here W = weight of hammer in tons or in pounds (the safe load is considered as in the same unit); H = its fall in feet; and S = the penetration in inches under the last blow. Results thus obtained, when compared with actual tests, show that this formula has a factor of safety varying from 2 to 7 or 8. It can be used properly, however, for comparatively stiff material only, for in soft material where long piles are to be used, it fails to give rational results.

In locations where great depths of mud are found, piles are often driven that do not find a solid foundation, and the driving might be continued indefinitely, but, after leaving such piles for a few days, it is often found that several blows are required to start them again. This indicates that their bearing power has increased after the driving has stopped. It is a common practice to accept such foundations for certain structures as the best that can be secured, although they sometimes yield. In bridge construction, however, the success or failure of the structure depends much upon the foundation and too much care can scarcely be given to this part of the work.

LOCATION, PROFILE, AND RECORD OF SOUNDINGS.

It often happens that, after having tested the foundation and after considering the suitability of the material found, together with the elevation at which this material is available, it becomes desirable to shift the location of the bridge in order to secure a more economical substructure. For example, a suitable material for foundation may be found at a more convenient elevation in one place than in another, and this may materially reduce the cost of piers and abutments without injuring the alignment of the road seriously. In some cases it may even improve the alignment.

A survey and profile of the location should be made to establish the grade of the road. From these the amount of excavation and back fill may be determined, as well as other quantities, distances, and elevations needed in preparing plans and in the execution of the work. Plate III will serve as a typical drawing of such a plan, showing the old and the new locations of the bridge, the elevation of the rock foundation, the new grade line, and the limits of the cuts and fills required.

Plate IV illustrates the improper location of a bridge by building it at an angle with the road instead of at an angle with the stream. It should be noticed that the general alignment of the road is practically straight, and that the sharp, dangerous curves at the bridge are entirely unnecessary and are caused by the poor location. Conditions similar to these exist in many places and should be avoided where new bridges are being built.

TYPES OF CULVERTS.

The simplest type of bridge or culvert that will be considered in this bulletin is the wooden plank floor bridge for very short spans. This may be strengthened for increased spans, up to certain limits, by supporting the floor upon logs or sawed timbers. The life of timber, especially in bridges and culverts, is at best only a few years, in some cases ten, but usually, in the flooring at least, it is not more than three years. The price of timber is constantly advancing, and the liability of accidents from misplaced, worn-out, or broken plank is very great. While a timber bridge admits of theoretical design, there is no real need for its use to be encouraged, and it is the purpose of this bulletin to deal with types of construction of a more permanent and substantial nature, such as concrete and steel.

CONCRETE SLABS, T-BEAMS, AND REINFORCED CONCRETE.

The simplest form of concrete construction for bridges or culverts is the concrete floor or slab, corresponding to the wooden plank floor mentioned above. The concrete slab may be used for greater spans

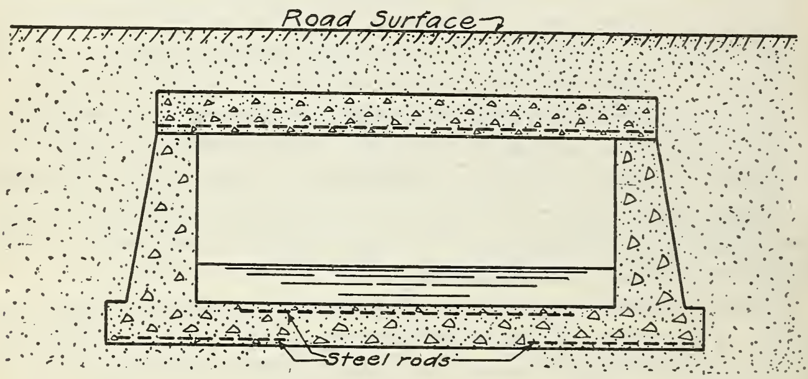
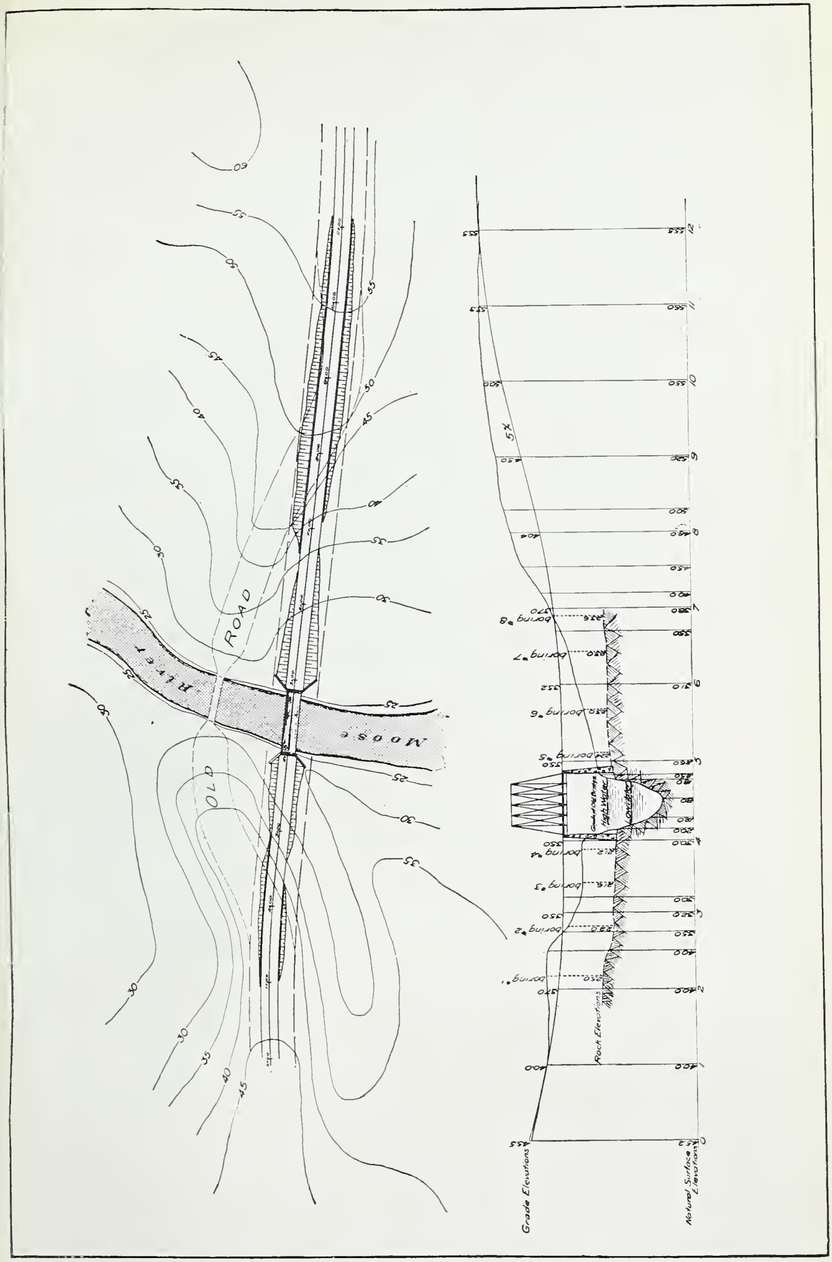


FIG. 2.—Reinforced concrete floor, for distributing pressure over a greater area and for protecting foundation from erosion.

than the plank floor, and it may also be strengthened for greater spans by constructing concrete beams beneath the floor to support it. This is then known as the "T-beam" type of construction, from its resemblance in form to the capital letter T. The tops of the letters are built adjacent to each other or in one continuous slab in such a way as to form the floor for the structure.

These types of concrete construction may be strengthened further by placing steel rods, expanded metal, or woven-wire cloth near the bottom of the slab, and steel rods near the bottoms of the beams. The advantages of using the steel reinforcement are that it has a greater tensile strength than concrete and that its location in the lower part of the concrete slab or beam brings it into tension when the



LOCATION MAP AND PROFILE, SHOWING PLAT OF SURVEY FOR A PROPOSED BRIDGE.

THE IMPROPER LOCATION OF A HIGHWAY BRIDGE.

[Note the short, sharp curves in the road, owing to the improper location of the bridge.]

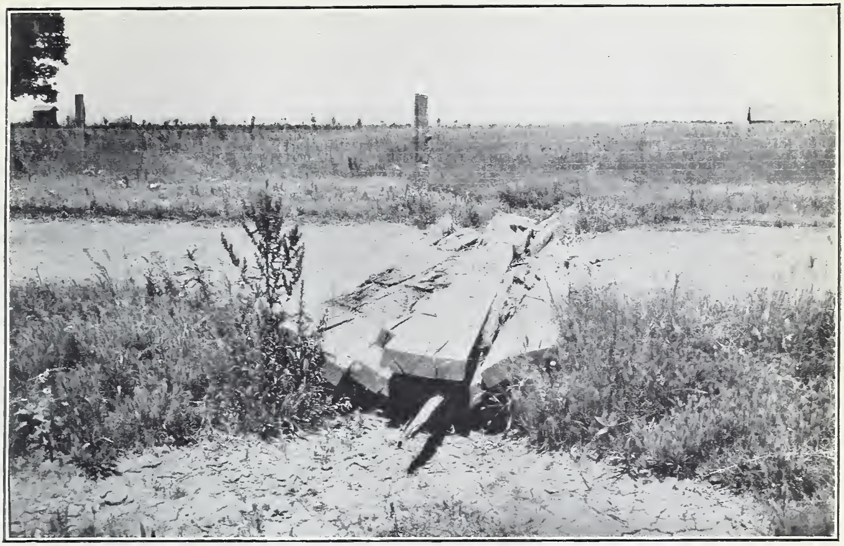
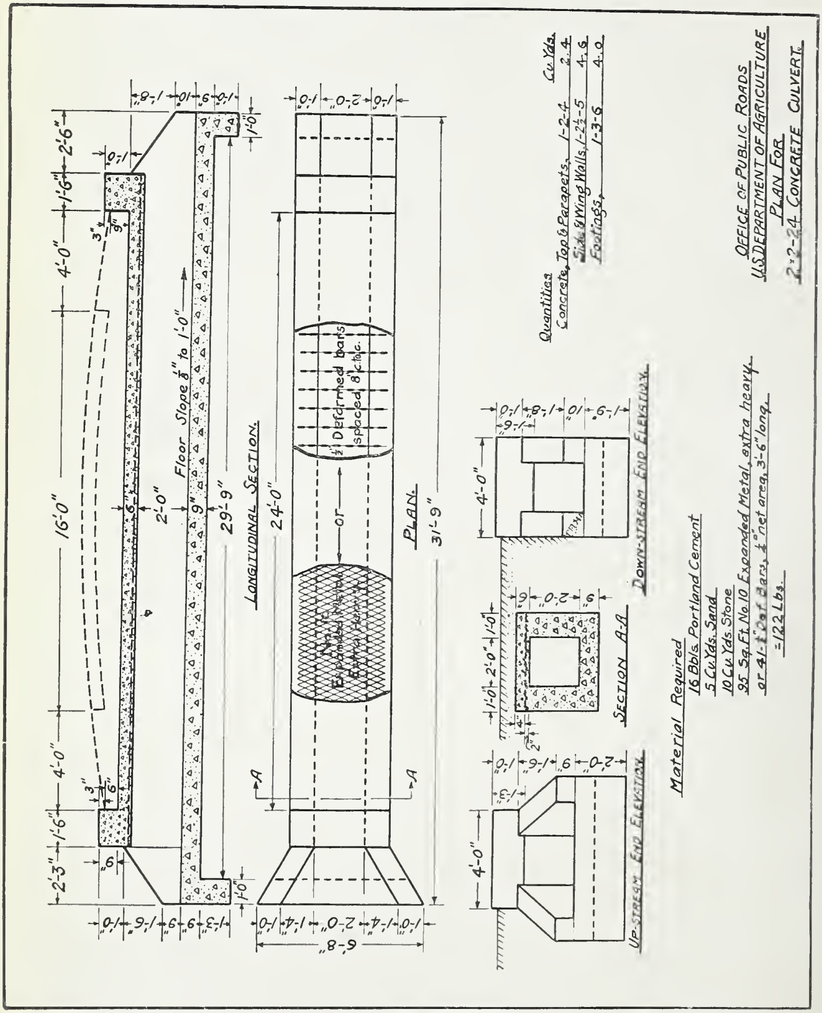


FIG. 1.—A TYPE OF CULVERT TO BE AVOIDED.

FIG. 2.—A BETTER TYPE OF CULVERT.



PLAN FOR A CONCRETE BOX CULVERT.

beam is loaded. (Fig. 2.) Moreover the compressive strength of concrete is greater than its tensile strength, and therefore the steel strengthens that part of the concrete structure which is subject to tensile stresses and is most liable to fail first.

This method is therefore more economical and makes it possible to bridge greater spans, within practical limits of cost, than can be done with plain concrete alone.

BOX CULVERTS.

The application of the concrete slab is to be found first in the construction of box culverts. Public highways in this country are crossed by many small open ditches. Many of these ditches are provided with wooden stringers and plank floors, which, however, are so nearly worn out and are in such poor condition that they do little more than invite accident (Pl. V, fig. 1). There is continual annoyance and expense in keeping these in repair, and this may all be avoided by building small concrete box culverts at these places (Pl. V, fig. 2).

The box culvert gets its name from its similarity to a box with open ends. It has a floor, which may be of plain concrete or may be paved with stone. The two sides and wing walls at the two ends may be of plain concrete or reinforced with steel, but the cover and parapets should always be of reinforced concrete.

The sketch shown in Plate VI is made from a working plan prepared in the Office of Public Roads for a concrete box culvert, which has an opening 2 feet wide by 2 feet high, and forms one of the set of standard plans previously referred to.

This type of construction is practical under the majority of conditions for spans up to about 8 feet, which, as a matter of fact, forms a large percentage of all the culverts needed. Conditions may occur where it will be practicable to apply the box type, with some modifications, to greater spans than those mentioned, such as where the foundation is soft or liable to much erosion from swift currents. The floor may then be reinforced with steel, so that it will have greater strength to act as a beam to distribute the load over a greater area. It may also be extended back of the side walls to act as a footing. With suitable "cut-off" walls to prevent currents of water from running beneath this floor, the foundation will be well protected from erosion. Under such conditions this modified type, with further modifications in the cover, which will be discussed later on, may be practical for spans up to 20 or 30 feet. Figure 2 illustrates the principle under discussion. Here the reinforced concrete floor serves the same purpose as the logs illustrated in figure 1, but the result is more permanent.

REINFORCED CONCRETE-SLAB CULVERTS.

The length of the spans over which reinforced concrete slabs may be built within the limits of practicability and safety depends much upon the loads to be carried. The depth and amount of fill over the culvert, which may distribute the effect of the concentrated load, is also an important factor.

On main roads, where concentrated loads, such as road rollers or traction engines, are to be provided for and the depth of fill over the culvert is sufficient only to provide a cushion of earth from 1 to 2 feet in depth, the concrete slab is practical for spans up to about 10 or 12 feet, while for greater spans than this, under these conditions, other types better adapted to the longer spans should be used. These will be discussed further on (cf. pp. 14–16).

Under conditions of less severe loading the spans for the slab may be increased up to 16 or possibly 20 feet, but it does not seem advisable to use them for these greater spans in view of the possibilities of a nominal future growth of traffic requirements.

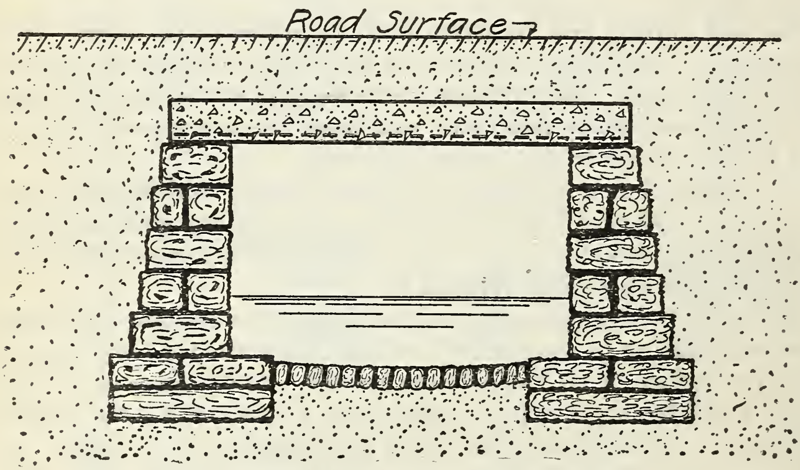


Fig. 3.—Reinforced concrete slab on masonry abutments.

MASONRY WALLS WITH CONCRETE SLABS.

In some localities conditions may be favorable for building the footings and side walls of quarried or suitable field stone laid in cement mortar. While these will not prove more satisfactory than good concrete, it may be a matter of economy to do this, because of the saving in expense in crushing the stone for concrete. The reinforced concrete slab may be built quite as well upon such walls.

There are also many cases where masonry walls are already built, but have a poor wooden floor for the bridge. These floors may be replaced with a substantial reinforced concrete slab, which will be permanent.

Traffic should not be allowed directly on the concrete surface of the slab. Consequently it may be necessary to take off the top of the masonry abutments, so that the slab may be set low enough to allow an earth cushion about 18 inches in depth to be placed on the concrete slab. There are also many other locations where the present bridge is set so low that it improves the grade of the road to construct the slab on the masonry abutments as they are found and then raise the grade of the road by placing the earth cushion over the slab (fig. 3).

REINFORCED CONCRETE T-BEAM CULVERTS.

The reinforced concrete T-beam type of construction supplements the slab type and begins to be practical in point of economy at the point where the slab ceases to be economical—that is, for spans from about 10 to 12 feet and more—under the conditions of concentrated loads, such as road rollers or traction engines. This type of construction has been designed for spans up to 50 feet long, but whether or not it is practical for spans as great as that may depend upon several conditions, which must be carefully determined in each individual case. (Pl. VII.)

CONCRETE-STEEL I-BEAM CULVERTS.

One of the best types of culverts for spans from 10 to 30 feet long is the steel **I**-beam incased in concrete, upon which rests a relatively thin concrete slab which forms the cover for the culvert. The slab is designed to carry the load for a span equal to the distance from center to center of the steel **I**-beams, while the beams are designed to carry the load over the clear span from one side wall or abutment to the other.

Among the best features of this type of construction are its safety and ability to withstand severe and unfavorable conditions, such as the unequal settlement of abutments, which may cause cracks in the concrete that would cause other types to fail. In this type, however, the load is carried principally by the steel **I**-beams, whose strength is not destroyed by the settlement of the abutments.

Many structures of this type have been built without incasing the **I**-beams in concrete, but by merely painting the beams instead, to protect them from rust. The painting, however, must be repeated every few years, at some considerable expense. There is, of course, a great possibility that this painting may never be done, and the better way is decidedly to incase the beams in concrete during the construction, and thus protect them permanently.

This type also admits of arch construction between the beams for the floor system. By this means space may be saved in the depth of the floor system that may be of value in locations where the area

of the waterway or the "head room" is a controlling factor. Plate VIII is made from a working plan prepared in the Office of Public Roads for a 24-foot span concrete steel I-beam culvert.

ARCHES.

The stone arch is one of the oldest types of bridge construction known, and dates back to a period about 4,000 B. C.[1] Many existing bridges are evidence of its great permanency and durability.

The arch also presents features which make this type of construction at times both practical and very attractive in design. It provides an economical and serviceable bridge, and at the same time harmonizes with the beauty of nature in undertakings of landscape development.

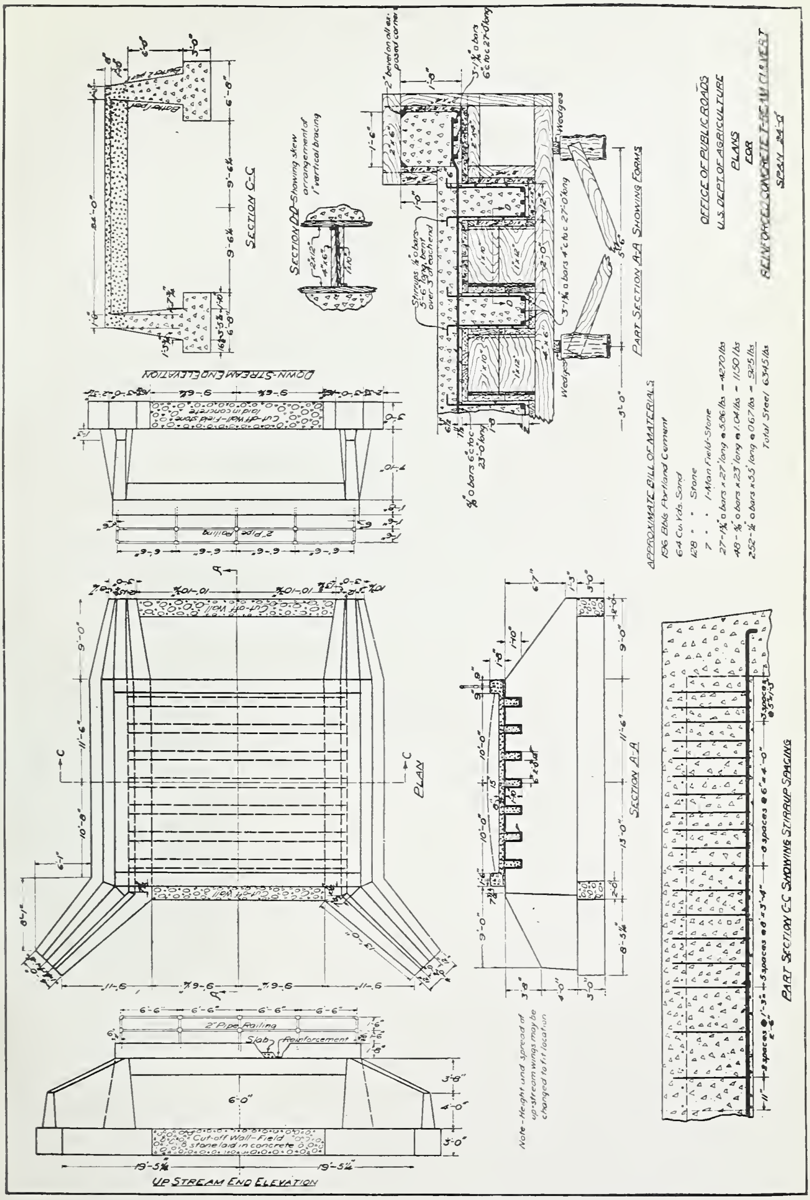
The arch may be constructed of cut stone, plain concrete, reinforced concrete, or steel. It is one of the most difficult types of bridge structures to design. Its strength depends much upon an unyielding foundation, and it requires absolutely first-class materials and the highest skill in its construction. It is a type of structure which should not be undertaken by inexperienced builders, or with haphazard methods. The services of a capable engineer should be secured, and with proper materials, thorough construction, and favorable local conditions, the arch is an economical and desirable type of bridge construction.

PLAIN CONCRETE ARCHES.

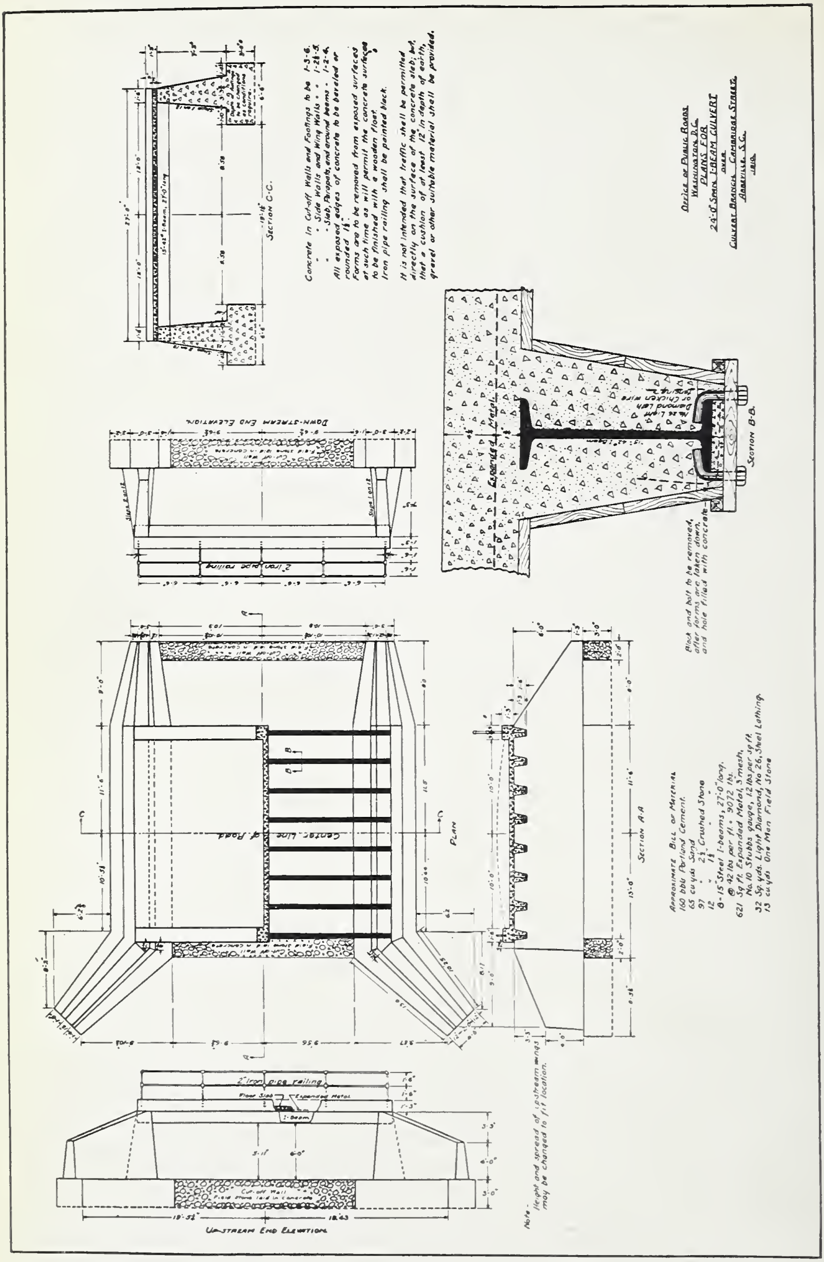
The arch culvert is well adapted for locations in deep ditches or ravines, where there is an abundance of "head room," and it may be built over spans from 2 feet up. Many have been built over spans of from 50 to 70 feet in length. The Connecticut Avenue Bridge in Washington, D. C., consists of a series of five arches, each 150 feet in span and built of plain concrete. A bridge in Germany has a single arch span of 215 feet, built of plain concrete. These two structures are rather exceptional, however, and are mentioned because of their general interest and not because it is intended to treat in detail of them or of structures of their magnitude in this bulletin. There are some noteworthy structures with a series of arches, and among them may be mentioned the railroad bridge at Rockville, Pa., which consists of 48 arches, each having a span of 70 feet.

The illustration shown in Plate IX is made from a working plan prepared in the Office of Public Roads for a plain concrete arch-culvert with a 6-foot span, which may be of service more often than those of larger spans.

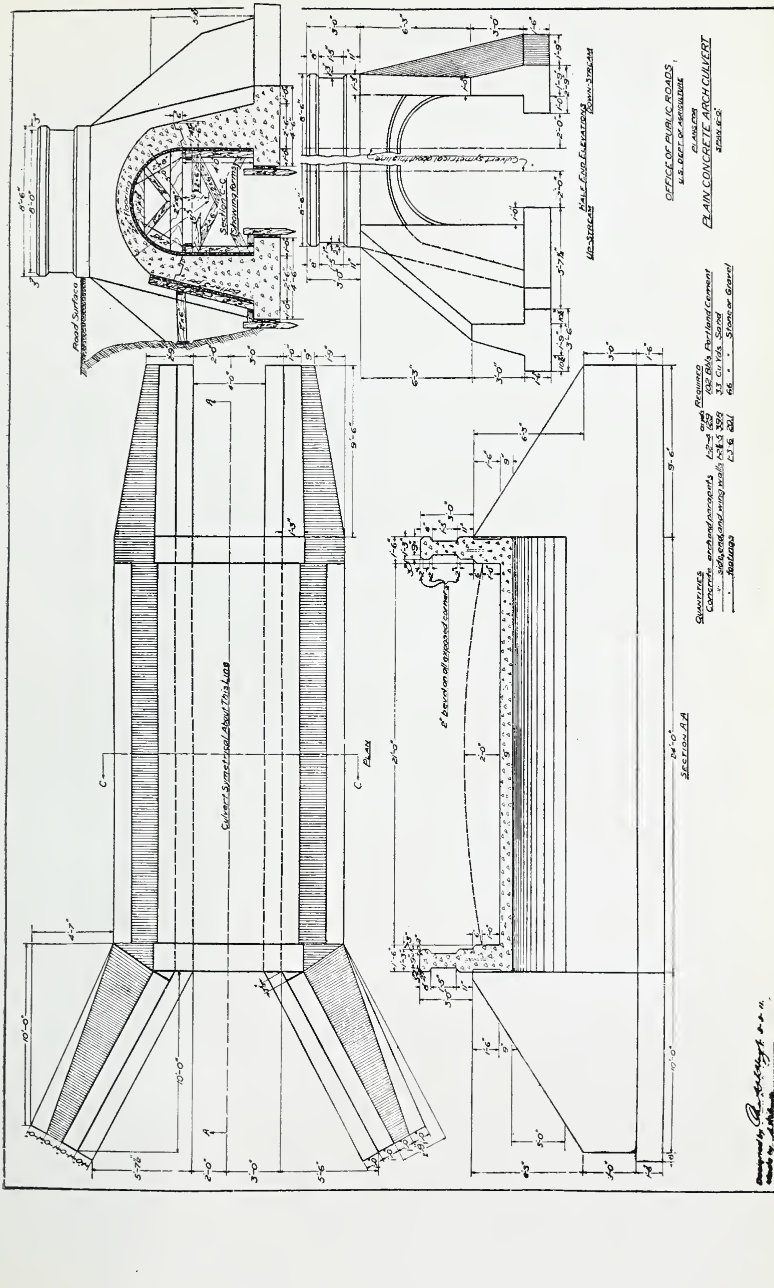
[1] Hilprecht, "Explorations in Bible Lands during the Nineteenth Century." Quoted on p. xiii, M. A. Howe, "A Treatise of Arches."



PLAN FOR A 24-FOOT T-BEAM CULVERT.



PLAN FOR A 24-FOOT CONCRETE-STEEL I-BEAM CULVERT.



PLAN FOR A PLAIN CONCRETE ARCH CULVERT.

The difference in the cost between an arch culvert for this span and that for a box culvert of the same span is not a matter of much importance. The advantage, if there is any, of the arch over the box type occurs very probably from the fact that no steel reinforcement is required for this arch as designed in the accompanying drawing.

REINFORCED CONCRETE ARCHES.

The reinforced concrete arch has an advantage over the plain concrete arch in the fact that the curve of the reinforced structure may be made more nearly flat than the plain concrete arch, and thereby save in the total height of the structure. This permits it to be used where it otherwise could not be. Under favorable conditions there may be an additional advantage in point of economy, although this can not be stated generally as true in all cases.

The steel reinforcement in the arch serves the same purpose as in the concrete slab—that is, to increase the strength of the arch rib where the concrete has excessive tensile stresses. In some cases, however, the concrete is also reinforced against compression. It is also possible, when steel reinforcement is used, to reduce the quantity of concrete in the arch rib from the amount that would be required for a plain concrete arch. The reinforced-arch type of construction may be used for practically the same spans as stated for the plain concrete arches.

FOOTINGS.

Footings for piers, abutments, and wing walls may be required for the purpose of distributing the pressure caused by the weight of the completed bridge structure and its "loadings" over a sufficient area to keep the pressure per square foot within the amount that will be carried safely by the material composing the foundation. In some cases, where the wall is designed for a gravity section—that is, without reinforcement—no footings will be required. This occurs, for example, where the side walls rest upon rock for a foundation. If the wall is of the reinforced-concrete type, then footings are practically always required. The cause for many broken wing walls is the lack of suitable footings under them.

As a matter of practical convenience in construction, footings are very generally built to "true up" uneven places in the foundation, and they are built up to some convenient elevation upon which the walls or piers rest.

The width of the footing is determined from the load to be carried and the bearing power of the foundation material. Its depth is determined from its width and the load carried; and, if constructed

of plain concrete or masonry, its depth should be equal to its projection from the pier or wall, or even greater. The depth of the footing required to carry a load may be reduced somewhat by the use of steel reinforcement placed near the bottom to strengthen the projecting portions of the footing.

Another consideration that must not be overlooked in the construction of the footings is their liability to be undermined. They may, however, be protected by "riprapping" or paving around them, or by "cut-off" walls across the stream to prevent erosion of the stream bed at the location in question.

ABUTMENTS AND WING WALLS.

In view of the practice of the past, there is great need for the consideration of this part of the subject.

In many cases abutments and wing walls have not been built at all, but the four corners of the bridge span have been set on cylindrical piers or posts with possibly only a few planks to hold the earth approach. The rapid destruction of the planks and consequent sinking in of the earth approach often make dangerous holes at the two ends of the bridge. This type of construction is defective in the fact that it does not protect, but subjects the bridge and also its approaches to a greater possibility of being washed away by high water and swift currents. The damage thus caused is often more than the amount required to build substantial abutments and wing walls.

The abutment serves a twofold purpose: First, it supports the end of the bridge span resting upon it; and, second, it acts as a retaining wall for the material composing the approach to the span. The wing walls, too, serve as retaining walls and as a protection to the banks or slopes of the approach to the bridge from erosion by the water currents.

The abutment must then be designed, first, to support its load after the bridge is in place, and, second, to act as a retaining wall to resist the overturning forces of the material back of it before the bridge span is placed in position.

The wing walls must be designed to act as retaining walls. It is not the purpose of this publication to give a technical treatment of the principles of design, and it may be sufficient to say that, as a general principle, the thickness at the bottom of a retaining wall should be at least 40 per cent of its height. This thickness should be increased if the wall is surcharged—that is, where the filling back of it is higher than the wall.

Plate X shows a culvert washed away because there were no walls to protect it, and another culvert where substantial abutments and wing walls have been built.

PIERS.

The discussion of the subject of piers falls properly under the question of economic design. Whether or not it is economical to construct piers depends upon the relative cost of the different spans, and also upon the size of the piers required. The area of the waterway and the liability of piers to destruction by ice jams, logs, or floods, and the kind of foundation available are important matters and any one of them may be a controlling factor in the design.

From two designs for a concrete bridge with a 40-foot span and a 20-foot roadway, a difference of about $200 in the cost of the superstructure alone appears in favor of building two 20-foot spans, instead of one 40-foot span. From this amount the cost of the center pier must be taken to determine which is the more economical plan. Estimating the cost of concrete at $8 a cubic yard, including forms, it is possible to use 25 cubic yards of concrete for the center pier. This would limit its height to about 8 feet in order to make the cost of the two structures about the same.[1]

STEEL BRIDGES.

The steel truss for bridges is the result of much progress, extending over many years, in the science of bridge building, both in the matter of designing and especially in the material used for the structures.

There are a few existing bridges which are typical examples of the old cast-iron types, but they are now used sparingly by the lightest traffic and are entirely avoided by road rollers or other heavy vehicles. Steel is now used for practically all metal bridges because of its toughness and great unit strength, which results both in economy and in making it possible, as well as practicable, to bridge great spans.

The discussion of the subject of steel bridges in detail is too long to be undertaken in this bulletin and will be reserved until some future time. It is sufficient for the present to say that the use of steel for the entire bridge structure, except the flooring, bedplates, and a few details, is now practicable for essentially all spans. Whether it will be economical in the long run to build short steel bridges of spans less than 30 or 40 feet with rolled steel beams or some other material, such as reinforced concrete or concrete in combination with rolled steel beams, is a question which must be considered in connection with local conditions in individual cases.

There are two general types of steel bridges, the plate girders and the trusses. The latter include trusses with either pin or riveted joints. The plate girder consists of a relatively thin plate of steel,

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[1] These facts are used to illustrate the principle involved rather than for their exactness.

along whose edges are riveted steel angles or steel angles and plates for flanges and stiffeners to give the required rigidity or stiffness as a bridge member. The plate girder is a very stiff, rigid, and altogether excellent type of bridge and it is used for railroad purposes up to spans of about 100 feet (Pl. XI). It may also be used up to at least the same length for highway purposes. There is, however, one disadvantage in using this type of structure for spans greater than 40 or 50 feet for highway bridges; unless there exists at any given location special means for transporting and lifting in place such heavy members, or even riveting together the parts of such members when the spans exceed about 60 or 70 feet, it becomes a very difficult undertaking. Plate girders may be riveted in the shop and transported as one piece up to lengths of from 60 to 80 feet. In no case, therefore, should such heavy members be contemplated for highway purposes where there is difficulty in transporting and handling the girder as delivered by the railroad.

The steel truss is the type of structure most used for highway bridges. It consists of a framework of steel members fastened together at joints by rivets or pins. The depth of the truss for long spans now usually varies so as to make parts of the upper chords have different inclinations to a horizontal, with the inclination greatest near the ends of the span. The posts or compression web members are usually vertical, while tension web members are inclined and run from the foot of one post to the top of the next member, or vice versa.

There are still a few types of trusses used to which are given the names of their original inventors or proposers, such as the Pratt truss, the Howe truss, or the Warren truss, as well as some others.

Formerly the Howe truss with upper and lower chords and compression web members of timber, but with wrought-iron tension web members was extensively built. It has now gone out of use, except in some remote districts where economy of first cost is absolutely essential. In these bridges cast-iron joint blocks were used at the joints where the web members intersected the chords.

The Pratt type of truss, more or less modified frequently in consequence of the varying depth of truss, is much used and makes an excellent style of bridge. It is adapted to almost any length of span from 100 feet up.

The Warren truss with riveted joints, formerly much known as "a lattice girder," is an excellent bridge for highway purposes for lengths of span from 60 or 70 up to 100 feet or more in locations where the plate girder would be too expensive. In fact, except for locations where the operation of riveting in the field is too troublesome or expensive, this type of bridge has great excellence for almost any length of span up to as much as 200 feet.

FIG. 1.—DESTRUCTION OF A CULVERT CONSTRUCTED WITHOUT WING WALLS.

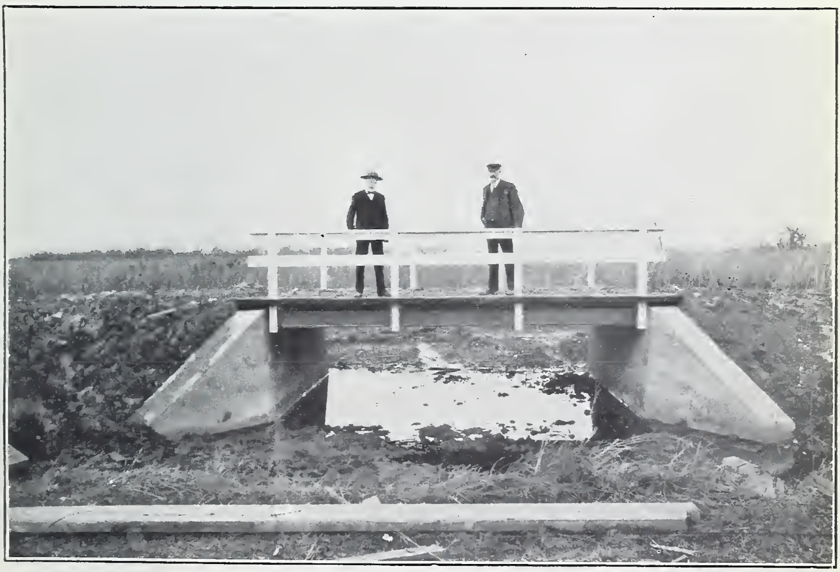
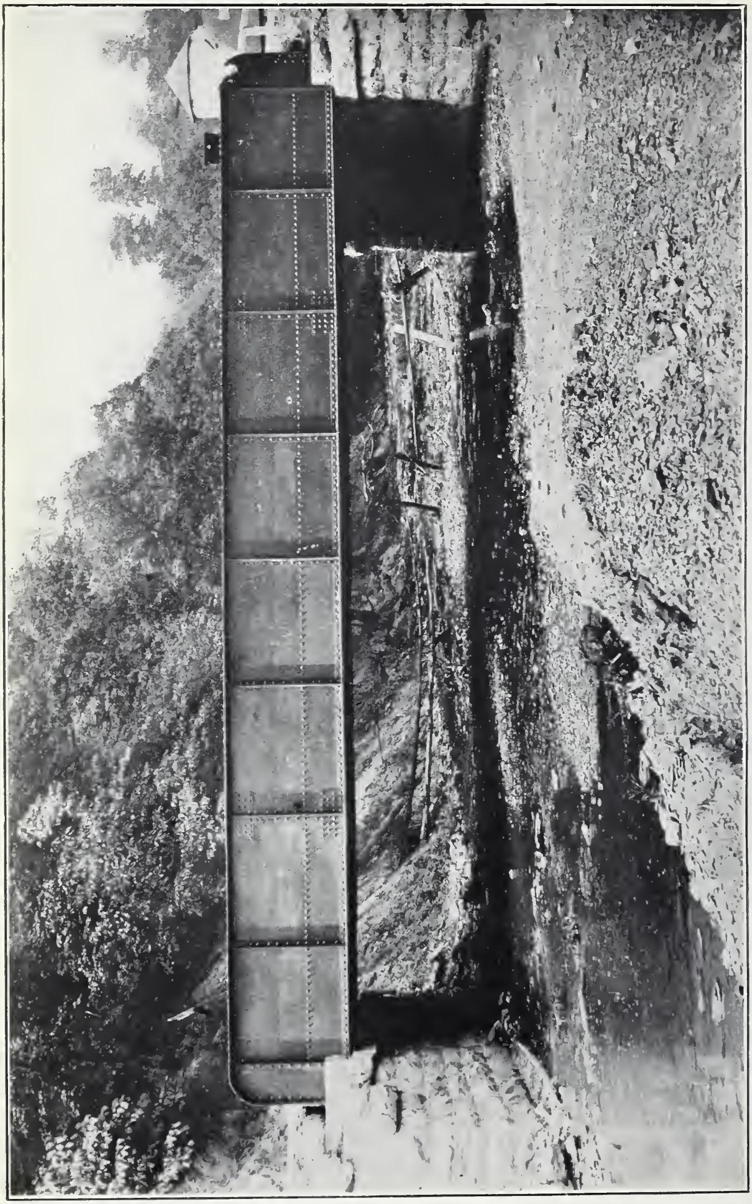
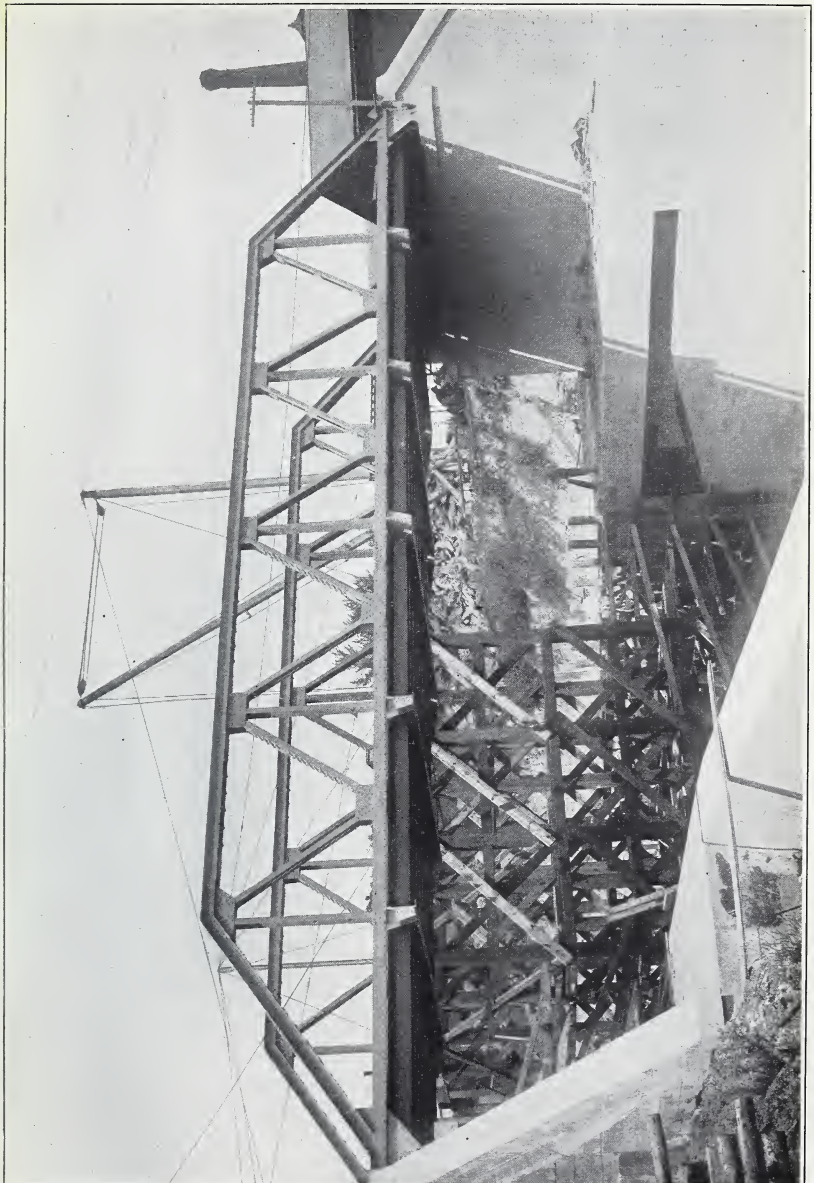


FIG. 2.—CULVERT WITH SUBSTANTIAL ABUTMENTS AND WING WALLS.



A SUBSTANTIAL EXAMPLE OF THE PLATE-GIRDER TYPE OF HIGHWAY BRIDGE (60-FOOT SPAN). BUILT IN PENNSYLVANIA.



FORT MILLER BRIDGE OVER CHAMPLAIN CANAL, FORT MILLER, N. Y.

[6 panels of 13 feet 7 inches=81 feet 6 inches span.]

PAYNE'S BRIDGE AND ABUTMENTS OVER CHAMPLAIN CANAL, FORT MILLER, N. Y.

[11 panels of 14 feet = 154-foot span.]

FIG. 1.—CONCRETE ARCH ON A MASSACHUSETTS STATE HIGHWAY.

FIG. 2.—CONCRETE SLAB CULVERT ON A MASSACHUSETTS STATE HIGHWAY.

CONCLUSION.

In conclusion, it may be said that the relation of culverts and bridges to the general movement for the improvement of our public highways is intimate. The desirability and economy of building these structures of durable and permanent material, or according to intelligent or economic design has not thus far been actually recognized in practice throughout the United States. The expensive and unsatisfactory method of repairing the old and inadequate structures of the past or of fording the streams is still continued.

Modern traffic now demands that the construction of bridges and culverts shall keep pace with industrial development. The administration of these matters in the United States is placed largely in the hands of local officials, who are scattered as individual units throughout the country. In many of these localities the amount of this class of work under the jurisdiction of one local official has apparently not been sufficient to warrant securing the services of a capable engineer in connection with this work.

ASSISTANCE RENDERED BY THE OFFICE OF PUBLIC ROADS.

The work of the Office of Public Roads, Department of Agriculture, is for the purpose of securing the improvement of all public highways throughout this country, and in connection therewith highway bridges and culverts should be given their full share of attention. In consequence, the office will send an engineer whenever practicable, to confer with local officials, upon their request, concerning this class of work; to make inspections, recommend such types of construction as are adapted to given locations, and give such other information and assistance as may be practical in the individual case.

In addition to this it is intended to issue other bulletins giving designs, specifications, and general information for small culverts and bridges.

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